Fundamental Studies of Mechanical and Tribological Properties of Ultrananocrystalline Diamond (UNCD) Thin Films and Application to MEMS

Scientific Achievement:

We studied the mechanical and tribological properties of ultrananocrystalline diamond (UNCD) thin films. The UNCD films were produced using the ANL patented MPCVD method (CH_4/Ar chemistry) that induce growth via C_2 dimers insertion in the lattice of the growing film yielding a material characterized by 3-5 nm grains and atomically wide grain boundaries. We fabricated MEMS cantilevers and bridges with our UNCD films and performed initial measurements of fracture and flexural strength, showing excellent performance. We performed AFM studies of UNCD surface stiction as a function of nitrogen doping, which revealed that n-doped UNCD surface has lower stiction than undoped UNCD. These results indicate that UNCD has great potential for application in microelectromechanical systems (MEMS).

The elastic modulus of UNCD thin films was measured using micro-cantilever and membrane deflection techniques (MDT). (MDE). Cantilever deflection tests on several freestanding UNCD cantilevers, 0.5 μm thick, 20 μm wide and 80 μm long, yielded elastic modulus values of 916 to 959 GPa. The tests showed good reproducibility by repeated testing on the same cantilever and by testing several cantilevers of different lengths. The largest source of error in the method was accurate measurement of film thickness.

Elastic modulus results from the membrane-based tests agreed well with those from the micro-cantilever-based tests. The membrane method yielded values of 940 to 966 GPa and showed less variability as well. Also, fracture stress for UNCD was found to vary from 1.4 to 4.6 GPa depending on the seed process used to grow UNCD films. The residual stress of the UNCD film was estimated to be 125 MPa. Although both methods yielded reliable values of elastic modulus, the (MDT) test was found to be more versatile since it yields additional information about the structure and material properties such as residual stress and resistance to fracture.

Significance:

The understanding of mechanical and tribological properties of UNCD films is critical both from the fundamental and applied science point of views. In addition, the fundamental and applied science performed within this program impact a new generation of technological developments in electronics, medicine, MEMS, telecommunications, sensors, and many other areas of application. The highly effective interplay of theory and experiment that has provided unique insights into the microstructure-property relationships of UNCD films at the microscale opens the way for future work focused on understanding UNCD properties at the nanoscale.

Performers:

O. Auciello, D.M. Gruen, J. A. Carlisle, J. Birrell, J. Gerbi, and X. Xiao (ANL), H. Spinosa and B. Peng (Northwestern University).

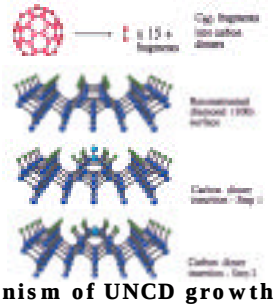
FWP: 58307

Fundamental Studies of Mechanical and Tribological Properties of Ultrananocrystalline Diamond (UNCD) Thin Films at MEMS Scale

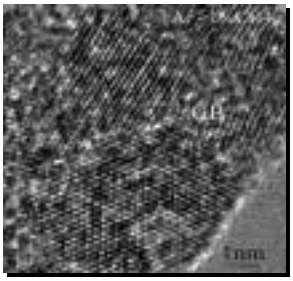
Synthesis and Characterization of UNCD Films

We performed studies of mechanical properties of UNCD films at the MEMS scale by fabricating cantilevers and bridge structures. We used a new microwave plasma CVD system assembled in MSD.

MPCVD System

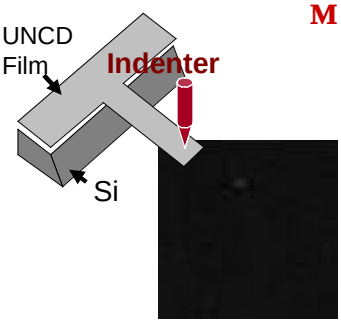


Mechanism of UNCD growth: Insertion of C_2 dimers into surface of growing film

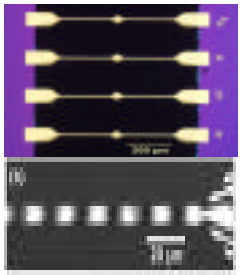


High resolution TEM of UNCD

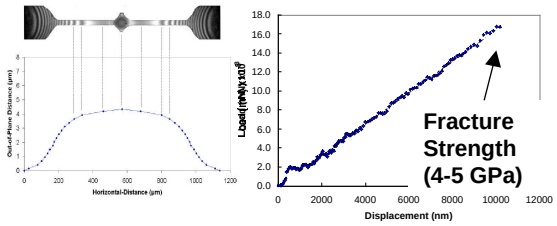
Measurement of mechanical properties of UNCD films



Schematic of cantilever method & SEM picture of UNCD cantilevers produced for measurements



UNCD membranes & optical picture of deformed membrane that yields strain and fracture strength



Optical picture of UNCD membrane deformed and load vs displacement curves that yields strain & fracture strength

Performers: O. Auciello, J.A. Carlisle, D.M. Gruen, J. Birrell, J. Gerbi, X. Xiao (ANL-MSD), H. Espinosa and B. Pen (Northwestern)